NOMADS
A Climate and Weather Model Archive at the National Oceanic and Atmospheric Administration

by

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Never before has the U.S. maintained a digital archive for its operational weather models, and an innovative data access philosophy promotes interoperable access across the geosciences.

Abstract

An on-line archive of real-time and historical weather and climate model output and observational data is now available from the National Oceanic and Atmospheric Administration (NOAA). This archive, known as the NOAA National Operational Model Archive and Distribution System (NOMADS), was jointly initiated in 2001 by the National Climatic Data Center (NCDC), the National Centers for Environmental Prediction (NCEP), and the Geophysical Fluid Dynamics Laboratory (GFDL). At present NOMADS provides access to real-time and historical (1) Numerical Weather Prediction (NWP) model input and output, (2) GFDL's Coupled Global Climate Models (CGCM) output, (3) global and regional reanalysis from NCEP and the National Center for Atmospheric Research (NCAR), and (4) limited surface, upper-air and satellite observational datasets from NCDC, NOAA's National Ocean Data Center (NODC), and NOAA's Forecast System Laboratory (FSL). NOMADS is but one of many similar data services across the U.S. and abroad, that are embracing and leveraging various pilot efforts toward distributed data access using agreed-to data transport and data format conventions. This allows for the interoperable access of various subsets of data across the Internet. These underlying community-driven agreements and the "OPeNDAP" data transport protocol form the core of NOMADS services as well as the capability for "format-neutral" access to data in many different formats and locations.

1.0 Introduction

Historical and real-time observation-based weather data are available though a number of different channels (e.g., the National Climatic Data Center (NCDC), which is responsible for the long-term stewardship of such data). In contrast, it is generally more difficult to obtain the input and output of high volume weather and climate models and reanalysis products and data files which are useful in numerous applications (e.g., model improvement, inter-comparison, validation and verification, extremes, climatology indices, and observational density spacing, and process studies). Although various historical access solutions exist (Rutledge, 1998) exist at various government laboratories and other institutions, a U.S. national archive of operational weather and climate models has simply not existed. To address the need for access to such model data, the National Climatic Data Center (NCDC), the National Centers for Environmental Prediction (NCEP), and the Geophysical Fluid Dynamics Laboratory (GFDL), have initiated the NOAA National Operational Model Archive and Distribution System (NOMADS). The primary goals of NOMADS are to act as a distributed front end service to NCEP, and to improve access to a suite of popular model data sets and observations, ranging from Numerical Weather Prediction (NWP) fields to Coupled Global Climate Model (CGCM) output to global and regional reanalysis. This paper describes the products currently available in NOMADS, its distributed and interoperable format neutral approach to data management, and the NOMADS system architecture and access tools currently available.

NOMADS servers exist at several locations in the U.S. including the real-time (R/T) server at NCEP (i.e., the R/T NOMADS), the GFDL Data Portal providing NOMADS compatible services for CGCM output and other data, and the real-time and historical NOMADS service at NCDC- the focus of this article.

2. The NOMADS Architecture

A new paradigm for sharing data among climate and weather modelers is evolving. It takes advantage of the Internet and relatively inexpensive computer hardware. In this new framework, scientists put their data unto a computer on the Internet. Software running on the computer allows outside users to see not only their local data but also data on other computers running this same software and data format descriptions. NOMADS participants serve their data sets through a client-server relationship, that is, the data sets are internet ready and the display is done by the user (their client). The NOMADS approach to data distribution is applicable to a large set of data products, including both observational and numerical model-based files, and can serve users interested in time scales ranging from those associated with synoptic weather features to those related to decadal to centennial climate issues.

The operational NOMADS server at NCDC has three independent ingests of model data. Data feeds are compared against each other, and repopulated if necessary on a daily basis before reaching the NCDC archive. This increases the possibility for a serially complete archive. Data quality control processes include checks on the raw Grib (WMO, 2001) model data and its associated transmission and file headers to the actual product, thus ensuring the highest possible quality of the data being archived and made available for distribution via NOMADS. NCDC works closely with NCEP if header or data errors are detected. Ingested models are also aggregated by model scale, projection, and forecast projection which, along with locally generated “index” files (a file and variable identifier utility) greatly increases the access speed of requested files or subsets. NOMADS ingests approximately 250,000 individual grids a day and with these index and file level optimizations, users can gain access to any single model variable within seconds. Additional operational NCDC ingest, archive, and quality control process are also performed including system loading, back-end disk clustering, load balancing and other backup capabilities to form a 24/7 operation.

3. Access Tools

From the early stages of its initial development the NOMADS team (Rutledge, 2001) sought to leverage off of existing data access approaches and to advance the concept of distributed format neutral data access. In other words, the approach involved drawing upon existing Agency and Institutional solutions while developing partnerships while promoting the Open source Project for a Network Data Access Protocol (OPeNDAP) transport protocol (formally called DODS), (Gallagher, 1995; Davis l999). As a result, NOMADS and other institutions provide access to distributed format neutral data in several ways and not necessarily under the NOMADS collaboration. The following access tools form the core of services while using NOMADS:

- The OPeNDAP http data transport protocol and the associated OPeNDAP Data Connector (ODC) program allows users to search for and retrieve datasets published by OPeNDAP data servers. OPeNDAP servers are located at major institutions around the world and serve a wide variety of data including: weather and climate data, satellite imagery, ocean and other data sets. The ODC (Figure 1) is downloaded to a users' desktop and provides a search and download capability to import the data into client applications like GrADS, CDAT, IDL, Ferret, Matlab™, SPSS™, Excel™, ArcView™ or into databases such as Access™ and Oracle™, and plot them with advanced graphics capabilities (many of these desktop tools are more fully described below). OPeNDAP and OPeDNAP enable clients form the core technologies to enable format neutral access across disparate systems and data formats. More information on OPeNDAP and the ODC can be found at the OPeNDAP Organization home page: http://opendap.org/.

- The NCDC NOMADS Interactive Web Browse, Plot, and Access tools (see the NOMADS Web Pages (http://nomads.ncdc.noaa.gov):

  1) "Plot"

  The NCDC NOMADS "Web Plotter" originally developed by NCEP, provides browse, limited on-line calculations, on and off-line access to data and variable subsets, long time series, Hovmueller diagrams, and advanced plot and animation capabilities. "Plot" includes the GrADS display client (Figure 2);

  2) "ftp4u"

  The ftp4u capability (Ebisuzaki, 2004) provides access to binary Grib data by sub-setting through time, space, and variable using traditional but enhanced file transfer protocol (ftp) processes. Data are provided in raw Grib format from either on-line or from NCDC's off-line archive. An email notification procedure is used if the data requested have to be retrieved from NCDC's off-line archive.

3) “http” and “Wget” and OPeNDAP Constraint Expressions

The Hyper Text Transfer Protocol (http) link provides simple file level access to download entire directories or files. This access method provides users with a well known process to collect multi-year requests. The “wget” utility is a freely available network utility to retrieve files from the World Wide Web, using http and FTP (File Transfer Protocol), the two most widely used Internet protocols. Since wget is a non-interactive downloading utility, you can execute scripts containing wget commands. While http access is familiar to many users, it is higly recommended that users learn to subset their requests either by variable or time period for high volume requests.

Another very powerful tool for accessing high volume NOMADS data is using the combination of http and an OPeDNAP “constraint” expression. Users can isolate individual model variables, dates, forecast time steps, and latitude and longitude using a Uniform Resource Locators (URL) to the data, with an OPeDNAP expression request appended to the URL. Then, when placed into a simple UNIX script this command can find and access multiple forecast projections form many model runs. NCEP has demonstrated this capability to interrogate approximately 10 Global Ensemble members and 1200 individual forecast probabilities in less than 1 minute over the Internet. See http://nomad5.ncep.noaa.gov/cgi-bin/var/ensprob1.pl for more information.

- The GrADS Data Server (GDS) combines both the GrADS (Doty, 2001), desktop analysis tool, a freeware client from the Center for Ocean, Land, and the

Atmosphere (COLA), and the OPeNDAP server to subset and exchange data in many formats with http. GDS data are fully OPeNDAP described to present the raw Grib (model binary format) and BUFR (WMO, 2001) as OPeNDAP compliant NetCDF files. Users execute an open "url" to data rather then keeping the data locally. The NCDC and NCEP NOMADS systems use GDS as its primary indexing, inventory, host-side data manipulation and sub-setting tool for users (an example GrADS display is shown as part of the "plot" function in Figure 2).

- The Climate Data Analysis Tool (CDAT) (Williams, 2002), is an open-source, Python-based environment for scientific calculations and graphics with focus on the needs of climate modelers. CDAT is primarily developed at LLNL in collaboration with the Open Source community, which includes other institutions such as the British Atmospheric Data Centre in England, the "Laboratoire des Sciences du Climat et de l'Environnement" in France. For more information on CDAT see Figure 4 and http://www-pcmdi.llnl.gov/software-portal/cdat/
- The Live Access Server (LAS) (Hankin, 2001) is a configurable Web server (Figure 5) designed to provide flexible access to geo-referenced scientific data. It can present distributed data sets as a unified virtual database through the use of OPeNDAP networking. NWP Grib and BUFR data is accessed by LAS though the GDS OPeNDAP capability. Ferret (Hankin, 1996) is the default desktop visualization application used by LAS, though other applications can also be used.
- The Interactive Data Viewer (IDV) from Unidata is a Java™ based software framework for analyzing and visualizing geo-science data in 2, 3 and 4 (time)

dimensions. The IDV brings together the ability to display and work with satellite imagery, gridded data, surface observations, balloon soundings, NWS WSR-88D Level II and Level III RADAR data, and NOAA National Profiler Network data, all within a unified interface (Figure 6). This desktop client can be downloaded from http://my.unidata.ucar.edu/content/software/IDV/index.html.

The significant advantage that these OPeNDAP enabled clients and servers have over traditional servers is that they provide direct access to data across multiple servers in the OPeNDAP format neutral (NetCDF) form. For example, data served by the GDS meet OPeNDAP standards so the raw Grib data are seen by clients as a standard NetCDF file. Users execute an open “url” to data rather then opening a local file on their disk. For high volume data requests, data can be requested by variable, temporal and spatial extents to reduce the overall volume of the request. Further, on many OPeNDAP enabled servers, the GDS in particular, users can request server side computations on these data and even caching the results of a previously calculated value in a temporary directory for use at a later date. To use the NCDC NOMADS GDS, navigate to the data of interest under the “gds” Web heading using a common Web browser. Following the directory structure based on model and date, locate the OPeNDAP metadata under the “info” section of the OPeNDAP files. Then, copy the “DODS url” (Figure 7) found there into your client as an appropriate open statement: (e.g. in GrADS: “sdfopen”). The client now has all the necessary information on that data file as to where it is, and how to decode, plot and retrieve individual data elements contained within that file. Once this information is known, users can then develop scripts to automate the “distributed” access of desired model data by date, time, model run or variable.

NOMADS also provides catalog level discovery and access for the Unidata Thematic Real-time Environmental Data Distributed Services (THREDDS) system, (Domenico, 2002), and therefore easy access to their OPeNDAP enabled IDV desktop client; metadata entries and direct portal access from the Global Change Master Directory (GCMD); as well as metadata descriptions as required under the Federal Geospatial Data Committee (FGDC) metadata schema. Formal NCDC archive documentation is also available for NOMADS datasets in text format at NCDC.

4. Data Availability

The NOMADS data management vision is to make model and associated data and information services uniformly available, providing seamless provision of and access to model input and output data, independent of format and how and where they are collected and stored (Rutledge, 2002). The NOMADS at NCDC has been distributing products since 2003 and today has over 16 terabytes of on-line data available for direct on-line access. Today the NCDC NOMADS provides up to approximately 5TB of model and observational data representing roughly one million downloads per month. Both the NCDC and NCEP NOMADS servers provide access to the model output as soon as it is available from the NCEP computers. The Real-Time NOMADS (R/T NOMADS) (Alpert, 2002) servers at NCEP provide short-term real-time services while NCDC NOMADS provides both historical and real-time data that provides for a “mirror” backup service to the NCEP server. This configuration allows researchers to transparently browse, extract and inter-compare on-line model data from the R/T NOMADS server at NCEP, and if needed, access historical data from the NCDC server. For a complete listing of data availability on the NOMADS systems at GFDL, NCDC, and NCEP see the NCDC NOMADS pages at: http://nomads.ncdc.noaa.gov. Table 1 provides the NWP data at NCDC while Table 2 provides their associated period of record. The products currently available on NOMADS include:

a. NCEP NWP Models[1]

- Global Forecast System (GFS) (Kanamitsu, 1989, 1991; Iredell, 2002)
- North American Mesoscale (NAM, formally Eta) (Black, 1997)
- NOAAPort/NCEP Rapid Update Cycle (RUC) (Benjamin, 2003)
- NCEP Spectral Statistical Interpolation (SSI) Global Data Assimilation System (GDAS) model input (sigma) and restart files (Du, 2004)
- NCEP North American Regional Reanalysis (NARR) (Mesinger, 2004)
- NCEP/NCAR R1 and R2 Global Reanalysis and AMIP-II (Kalnay, 1996; Kistler, 2001; Kanamitsu, 2002)
- Climate Data Assimilation System (CDAS) and the NCEP/NCAR R1/R2 Reanalysis (Kanamitsu, 1995; Ebisuzaki, 1998)
- NCEP Regional Special Model (RSM) (Juang, 1997)
- NCEP Global Ensembles (Toth, 2002, 2005; Zhu 2002)

1 The NCEP operational suite of models are updated at least yearly. For the latest information on model numerics and other documentation see the NCEP documentation pages at: http://www.emc.ncep.noaa.gov/; and the NWS Technical Procedures Bulletin updates at: http://www.emc.ncep.noaa.gov/gmb/STATS/html/tpblist.html

- NCEP Short Range Ensemble Forecasts (SREF) (Du, 2004)
- NCEP Climate Forecast System (CFS) coupled climate model (Saha, 2005).
- NCEP Ocean Wave (Tolman, 1999)
- NWS National Digital Forecast Database (NDFD) (Glahn, 2003).

Note: The NDFD and the NCDC archive of these data along with the capability for NOMADS format neutral sub-setting and access is currently under development. NCDC will archive all operational NDFD grids when available.

b. In situ Observations

- NCDC Global Historical Climate Network (GHCN) surface temperature and precipitation anomalies (Peterson, 1997)
- NCDC Integrated Global Radiosonde Archive (IGRA) upper air reference quality data set (formally the Comprehensive Aerological Data Set- CARDS) (Durre, 2005)
- NCDC Smith-Reynolds Extended Reconstructed Sea Surface Temperatures (ERSST) and climatologies (Smith, 2004)

c. Satellite and Radar Observations

- National Ocean Data Center (NODC) Advanced Very High Resolution Radiometer (AVHRR), Pathfinder Sea Surface Temperature (SST) analysis datasets provided through a link to NODC (Kilpatrick, 2001)
- Other satellite and Radar data are currently being developed with various partners for access to limited Geostationary Operational Environmental Satellite (GOES), data and the National Aeronautics and Space Administration (NASA) satellite and Radar data with Unidata via OPeNDAP

d. GFDL Coupled Global Climate Models (CGCM)

- GFDL CM2.0 climate model experiments: the current generation model (Delworth, 2005)
- GFDL CM2.1 climate model experiments (Delworth, 2005)
- GFDL_R30_c climate model experiments: previous generation model (Delworth, 2002)
- GFDL_R15_b climate model experiments: an older model (Dixon, 2002)

The GFDL Climate models are available at GFDL at: http://nomads.gfdl.noaa.gov/.

As of 00Z May 25 2005, the NOAAPort ingest for the NOMADS NCEP NWP data archive was discontinued. These reduced resolution and variable grids were removed in favor of the higher resolution and variable NCEP GFS and NAM grids. Additionally, by the time this paper reaches publication, new datasets and a new NCEP “Mirror” server will be established at NCDC. This mirror server will act as a backup to the Real-Time (R/T) NOMADS servers at NCEP, and provide new data sets for access and archive at NCDC.

Some of the most popular NOMADS datasets are more fully described below.

NCEP Ensembles

The Global Forecast System (GFS) Ensemble forecasts are available from zero to seven days at 6 hour intervals at 1x1 degree grid and zero to 16 day forecasts at 6 hour intervals on a 2.5x2.5 degree grid. As an example of an OPeNDAP service, the NOMADS team has developed a client application which accesses the NCEP Global Ensemble model forecast data to produce user selected weather element event probabilities. Probability estimates can be defined simply as the percentage of ensemble forecasts of the total number that satisfy a specified event for some weather element. Ensembles are composed of many model realizations and accessing many large files for small amounts of data at specific locations and for certain variables can be efficiently accomplished by the NOMADS GDS. The event probabilities are easily extended over ensemble model forecast times to show probability histograms defining a product for the forecast probability of user selected events. For access to the NOMADS Ensemble Event Probability page see: http://nomad5.ncep.noaa.gov/cgi-bin/var/ensprob2.pl

The NCEP Climate Forecast System (CFS)

The NCEP Climate Forecast System, (CFS, Saha et al. 2005) are available on the NCEP R/T NOMADS system providing monthly means and twice daily runs of 15 members initialized each month from 1981-2003.

NCEP North American Regional Reanalysis (NARR)

The NCDC NOMADS is NOAA's primary access point for the new North American Regional Reanalysis (NARR). NARR is a reprocessing of the historical meteorological observations using NCEP's regional forecast model and associated 3D-VAR data assimilation system. The products of NARR will be a new set of meteorological analyses covering the North American domain with a 32 km horizontal resolution, 3 hour temporal resolution and 50 hPa vertical resolution for October 1978 to the present. A 'merged' data set based on the analyses+fluxes on the AWIPS grid is available on NOMADS at approximately 5 TB (60 MB every 3 hours) in volume. The NARRMON dataset contains a monthly average (computed at NCEP) of all the fields in the NARR. The NARRMON-3hr dataset is a monthly average of all fields, separated into eight three-hour time periods for each day throughout a month. See Table X for more information.

Note for NARR users: The data for each analysis time is split into two files so that the data will be compatible with the software program, GrADS. For example, the "narr-b" file contains 3 hour forecast of the sensible heat flux whereas the “narr-a” file contains the average from the 0-3 hour forecast. For example:

Suppose we set GrADS to have only one time variable to read analysis and forecast files:

- file A: analysis at 2004-01-01-00Z
- file B: 3 hour forecast valid at 2004-01-01-00Z

GrADS allow you to combine data sets together so you can make a time series. If NOMADS combined all the "A" files together, GrADS users would set the time to 2004-01-01-18Z and make a successful plot. On the other hand if the A and B files were combined together, the GrADS client would not be able to distinguish between the analyses or the forecast valid time. To avoid this GrADS limitation, all the data were put into the "A" files except the forecasts that would cause the timing confusion. Most users will only require the "A" files while those users requiring a hydrological analyses increment for example, will require the "B" files.

GFDL Coupled Global Climate Models (CGCM)

The GFDL's CGCM's are available under the NOMADS framework including model output and documentation of experiments performed using GFDL's current generation of global coupled climate models named GFDL CM2.0 and GFDL CM2.1. These two models are being applied to decadal-to-centennial (deccen) time scale climate issues, including multi-century control experiments and climate change projections. To learn more about the GFDL CM2.0 and CM2.1 models and their output, one may visit http://nomads.gfdl.noaa.gov/CM2.X/.

The GFDL CM2.0 and CM2.1 medium resolution climate models consist of atmosphere, ocean, sea ice and land surface model components coupled together. The two CM2.x models differ in some of their dynamics and physical parameterizations. While the atmosphere and land surface components use a different grid than do the ocean and sea ice components, both CM2.0 and CM2.1 share the same grid resolutions The archived atmosphere and land surface model output is on a grid with approximately 2 degree grid spacing in the horizontal. While the atmospheric GCM utilizes 24 atmospheric levels, the vast majority of the atmospheric model output is stored on 17 standard pressure levels. The ocean and sea ice models grid resolution is approximately one degree in the horizontal with higher resolution in the tropics, and "tripolar" elements in the Arctic. The ocean model component has 50 vertical levels.

Model output from 20 experiments (10 each for CM2.0 and CM2.1) are accessible from the GFDL Data Portal (http://nomads.gfdl.noaa.gov/). These experiments were driven by forcing agents consistent with those requested by the Intergovernmental Panel on Climate Change (IPCC, 2001), for their forth assessment report (AR4), and are applicable to research projects associated with the U.S. Climate Change Science Program (CCSP). The 10 experiments include:

- One pre-industrial (circa 1860) control (300 years of output available).
- Three "Climate of the 20th Century" experiments (140 years each; simulating 1861-2000).
- Three Special Report on Emissions (SRES) climate change projections (A2, A1B and B1 scenarios) in which forcing agents vary from 2001-2100; the A1B and B1 experiments continue to year 2300 with forcing agents stabilized at 2100 levels.
- One “committed climate change" 100 year long model simulation, with forcing agents stabilized at year 2000 levels.
- Two idealized forcing integrations in which atmospheric CO2 increases 1% per year to twice (the 2X run) and four times (the 4X run) its initial value, and is then held constant for a minimum of 150 additional years (220 to 300 year experiment durations).

Some model output files from GFDL’s older R30 and R15 Climate Model integrations (Delworth, 2002) are still available for those interested in previous generations of GFDL coupled climate models. See the GFDL web site for more information on all these model integrations.

5. Other Applicable Technologies and NOMADS

To respond to these changing requirements and mission goals a flexible user access infrastructure must become increasingly robust, responsive, efficient, secure, adaptable and cost-effective. NOMADS users have the capability to sub-set high volume data, however some researchers and others require access to entire suites of high volume model data. One such effort that augments NOMADS for access to high volume model data is the Earth System Grid (ESG) (Foster, 2001). The Department of Energy's (DOE) Program for Climate Model Diagnostics and Inter-comparison (PCMDI), the National Center for Atmospheric Research (NCAR), and other DOE sites initiated and continue to develop Grid based intelligent filing systems and data management software to link storage devices located throughout the United States and the international climate research community. ESG uses the Globus™ Toolkit (Foster, 2004) grid technology among other services and data location and management techniques developed especially for Climate and other high data volume users. The latest U.S. climate models from GFDL and NCAR for the Intergovernmental Panel of Climate Change (IPCC, 2004) Model Inter-comparison Project (MIP) are being accessed through the ESG at PCMDI. Grid and Web based "Services" have emerged as viable technologies that are increasingly utilized by government laboratories, corporate institutions, and high performance computing centers around the world. Grid and Web services are being developed and used in diverse applications such as high-energy physics, medical imaging, meteorology, and business applications. Recently completed efforts to define grid software standards that align with standards from the World Wide Web, and Globus's adherence to these standards, have strengthened the interest and commitment of industry toward grid computing (Govett, 2004). It is the opinion of the authors that Web-based services will become an ingrained part of data access and computation in the near future as "Web Services" using XML (Bray, 1998) will become as transparent as http is today. One such exploratory effort SciFlow (Yunck, 2004) is a good example of distributed Web and Grid based service. Other model data access efforts for high volume model data access are being provided through Web-based Portals including the NCAR Community Data Portal (CDP, https://cdp.ucar.edu/) and NASA's earth science community especially through the Earth Systems Information Partners (ESIP) program. Finally, International efforts, especially in Europe (Lawrence, 2003), are advancing interoperable data and system access and computation for both the grid and the Web. This paper however, will not specifically address these technologies but are included herein for completeness.

NOMADS is monitoring the direction the open source and "Web and Grid services" communities are taking and leveraging these new tools as they develop. NOMADS is an active participant in many National and International exploratory efforts including the Committee of Earth Observation Satellites (CEOS, 2005) CEOS-Grid project; and member and contributor to the Global Organization for Earth System Science Portal (GO-ESSP, 2005). GO-ESSP is an international grass roots effort to address the distributed data access to models and associated data and actively working to resolve modelers' needs for inter-disciplinary research and access. More information on GO-ESSP can be found at: go-essp.gfdl.noaa.gov/.   Finally, NOMADS is currently working to include other model datasets namely from NASA a new collaborator, as well as other model data including the land (hydro) and ocean modeling communities.

6. Interoperable Data Management- the NOMADS Goals and Vision

Beyond improved and distributed access to models; the fundamental issue that NOMADS seeks to address is how NOAA and its partners can organize its data files from its distributed climate and weather models and related observational data into a cohesive presence that facilitates real-time and retrospective climate and weather model analysis and inter-comparisons. For the first time users can access model input, output, and observations to analyze and improve climate change and detection processes, to improve short-term NWP and seasonal forecasts, and to improve long-term global climate simulations under a distributed client-server framework. The goals of NOMADS are to:

- improve access to NWP and GCM models and provide the observational and data assimilation products for Regional model initialization and forecast verification,
- improve operational weather forecasts,
- develop linkages between the research and operational modeling communities and foster collaborations between the climate and weather modeling communities,
- promote product development and collaborations within the geo-science communities (ocean, weather, and climate) to study multiple earth systems using collections of distributed data under a sustainable system architecture, and
- act as a resource for the development of a long-term framework for systematic approaches to climate change detection efforts, climate and weather model evaluation, impacts studies, and other process studies.

To achieve this, NOMADS uses the OPeNDAP protocol and common data schema conventions, and suggests that new participants use and advance this service methodology and that data generators' and scientists work to provide their data in one of the many applicable data schema's and formats.

The NOMADS has been developed to address model data access needs as outlined in the U.S. Weather Research Program (USWRP) Implementation Plan for Research in Quantitative Precipitation Forecasting and Data Assimilation which states a need to "redeem practical value of research findings and facilitate their transfer into operations." The NOMADS framework was also developed to facilitate model and observational data inter-comparison issues as discussed in documents such as the Intergovernmental Panel on Climate Change (IPCC 1990, 1995, 2001, 2004) the U.S. National Assessment (2000), and the Climate Change Science Program (CCSP at: http://www.climatescience.gov). Finally, NOMADS directly addresses goals as outlined in the National Research Council (NRC, 2003) report "Fairweather: Effective Partnerships in Weather and Climate Services" Recommendation Number 5 that states:

> *The NWS should make its data and products available in Internet-accessible digital form. Information held in digital databases should be based on widely recognized standards, formats, and metadata descriptions to ensure that the data from different observing platforms, databases, and models can be integrated and used by all interested parties in the weather and climate enterprise".*

The NOMADS data management vision is to make model data and information services uniformly available to all elements of NOAA, (operational and research), as well as to external communities, thus providing seamless provision of and interoperable access to model data independent of format, or how and where they are collected and stored. NOMADS has been developed as a unified climate and weather archive providing Web access to information so that users can make decisions about their specific research, operational, and educational needs. This on time scales from days (weather), to months (El Niño), to decades and centuries (climate change).

7. Conclusions

A new paradigm for sharing data among climate and weather modelers is evolving. It takes advantage of the Internet and relatively inexpensive computer hardware. NOMADS participants serve their data sets through a client-server relationship in internet ready form. Both researchers and policy-makers alike now expect our national data assets to be easily accessible and interoperable, regardless of their physical location. As a result, an effective interagency distributed data service requires coordination of data infrastructure and management extending beyond traditional organizational boundaries.

NOMADS user access has seen a tremendous level of growth since its inception in 2003. The original vision to improve the linkages between the research and operational modeling communities has been extended to foster new collaborations between and among the climate and weather communities. It is hoped that these collaborations will not only promote product development but new collaborations within the geo-science communities (ocean, weather, and climate) to study multiple earth systems using collections of distributed data under an integrated sustainable system architecture.

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Figure 1. The OPeNDAP Data Connector (ODC) interface.

Figure 2. The NOMADS Web Plotter: A GrADS Animation example

Figure 3. Example "ftp4u" sub-setting capability

Figure 4. PCMDI's Climate Data Analysis Tools (CDAT) User Interface

Figure 5. NOMADS Live Access Server at NCDC: Model Inter-comparison on the fly

Figure 6. Unidata's Interactive Data Viewer (IDV) showing upper tropospheric wind data obtained remotely from a NOMADS server

Figure 7. GDS OPeNDAP "Info" and "url" directory information

Table 1. Data Availability on NOMADS

Table 2. Period of Record for NOAMDS Datasets

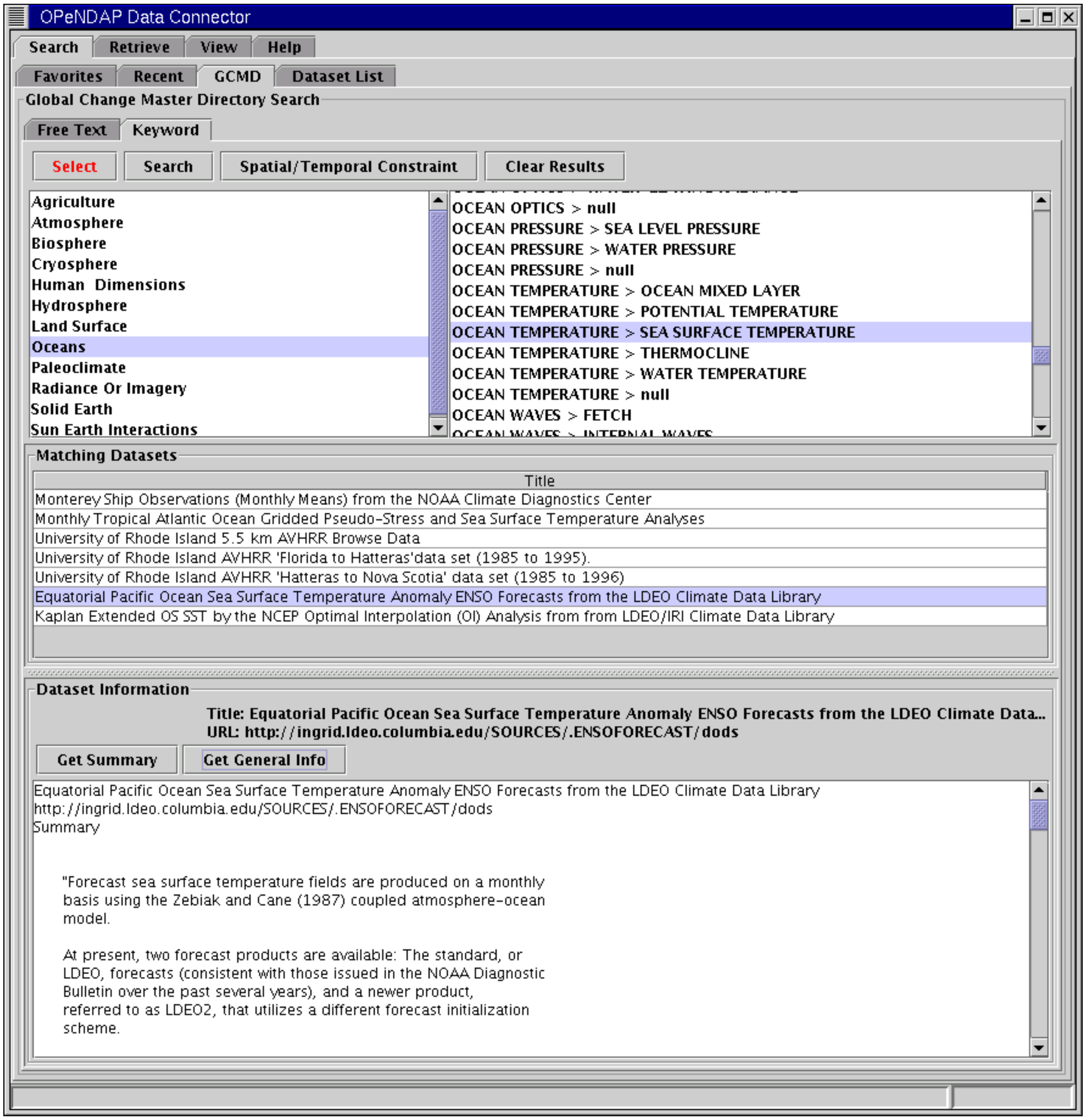

OPeNDAP Data Connector
Search
Retrieve
View
Help
Favorites
Recent
GCMD
Dataset List
Global Change Master Directory Search
Free Text
Keyword
Select
Search
Spatial/Temporal Constraint
Clear Results
Agriculture
Atmosphere
Biosphere
Cryosphere
Human Dimensions
Hydrosphere
Land Surface
Oceans
Paleoclimate
Radiance Or Imagery
Solid Earth
Sun Earth Interactions
OCEAN OPTICS > null
OCEAN PRESSURE > SEA LEVEL PRESSURE
OCEAN PRESSURE > WATER PRESSURE
OCEAN PRESSURE > null
OCEAN TEMPERATURE > OCEAN MIXED LAYER
OCEAN TEMPERATURE > POTENTIAL TEMPERATURE
OCEAN TEMPERATURE > SEA SURFACE TEMPERATURE
OCEAN TEMPERATURE > THERMOCLINE
OCEAN TEMPERATURE > WATER TEMPERATURE
OCEAN TEMPERATURE > null
OCEAN WAVES > FETCH
Matching Datasets
Title
Monterey Ship Observations (Monthly Means) from the NOAA Climate Diagnostics Center
Monthly Tropical Atlantic Ocean Gridded Pseudo-Stress and Sea Surface Temperature Analyses
University of Rhode Island 5.5 km AVHRR Browse Data
University of Rhode Island AVHRR 'Florida to Hatteras'data set (1985 to 1995).
University of Rhode Island AVHRR 'Hatteras to Nova Scotia' data set (1985 to 1996)
Equatorial Pacific Ocean Sea Surface Temperature Anomaly ENSO Forecasts from the LDEO Climate Data Library
Kaplan Extended OS SST by the NCEP Optimal Interpolation (OI) Analysis from from LDEO/IRI Climate Data Library
Dataset Information
Title: Equatorial Pacific Ocean Sea Surface Temperature Anomaly ENSO Forecasts from the LDEO Climate Data...
URL: http://ingrid.ldeo.columbia.edu/SOURCES/.ENSOFORECAST/dods
Get Summary
Get General Info
Equatorial Pacific Ocean Sea Surface Temperature Anomaly ENSO Forecasts from the LDEO Climate Data Library
http://ingrid.ldeo.columbia.edu/SOURCES/.ENSOFORECAST/dods
Summary
"Forecast sea surface temperature fields are produced on a monthly
basis using the Zebiak and Cane (1987) coupled atmosphere-ocean
model.
At present, two forecast products are available: The standard, or
LDEO, forecasts (consistent with those issued in the NOAA Diagnostic
Bulletin over the past several years), and a newer product,
referred to as LDEO2, that utilizes a different forecast initialization
scheme.

Figure 1.

NOMADS Interactive Web Plotter - Order # 1052 ./meso-eta-hi_218_20040529_1800_fff.ctl

PRESsfc 1000

18Z29may2004 to 06Z01jun2004

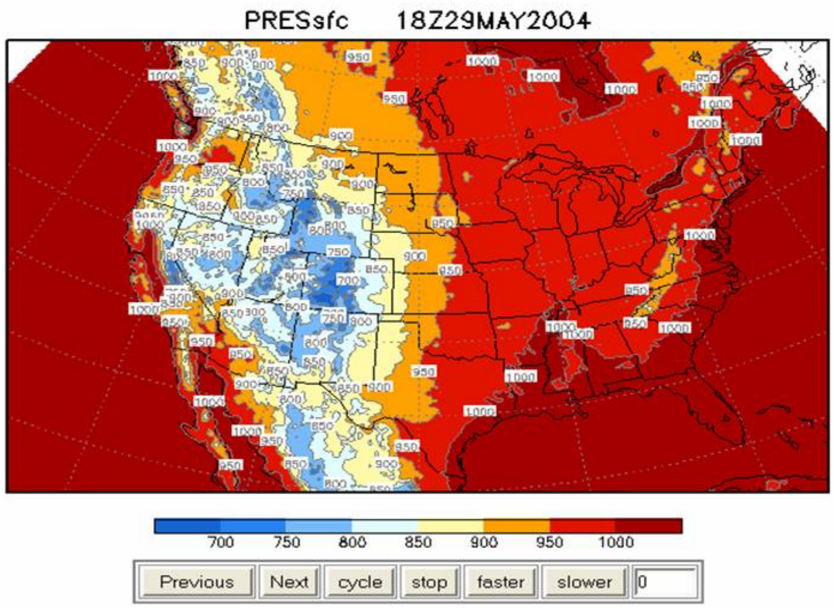
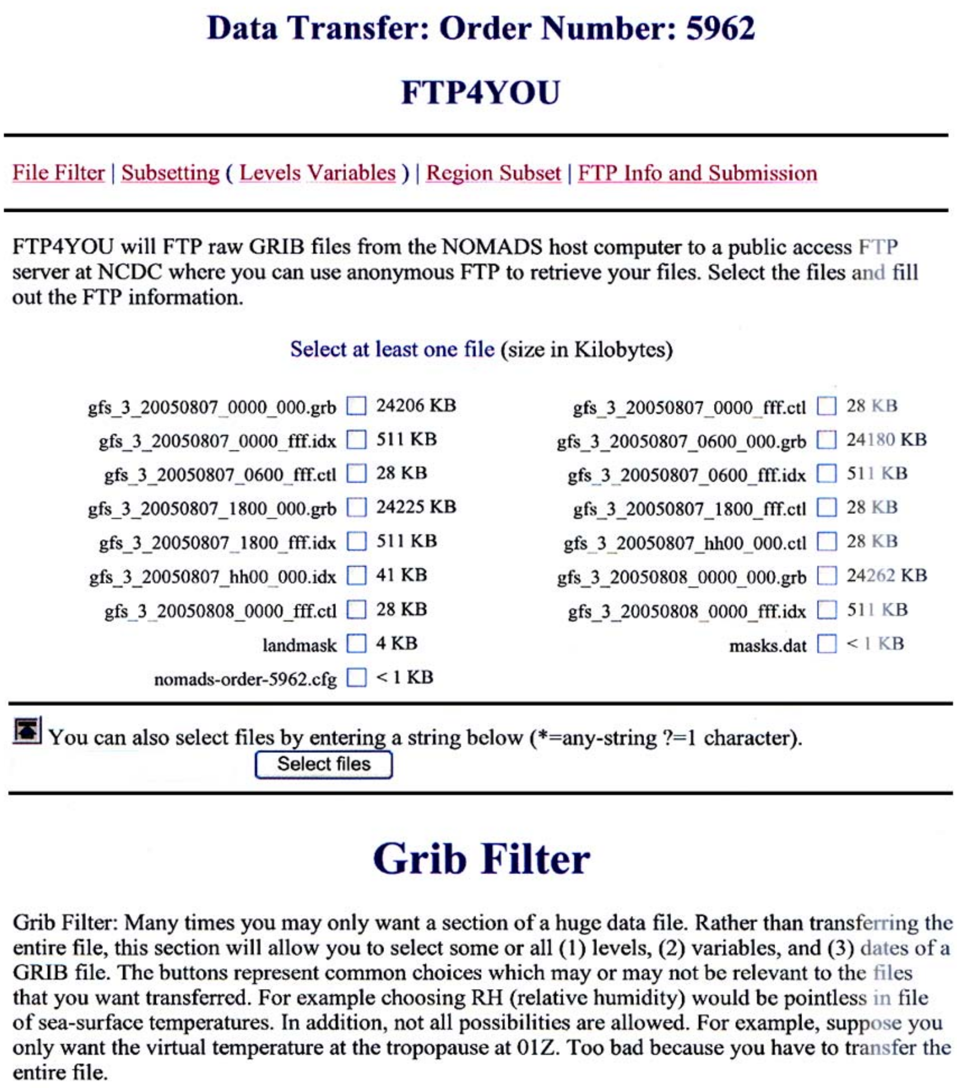


Figure 2.



Data Transfer: Order Number: 5962

FTP4YOU

File Filter | Subsetting (Levels Variables) | Region Subset | FTP Info and Submission

FTP4YOU will FTP raw GRIB files from the NOMADS host computer to a public access FTP server at NCDC where you can use anonymous FTP to retrieve your files. Select the files and fill out the FTP information.

Select at least one file (size in Kilobytes)

gfs_3_20050807_0000_000.grb	24206 KB	gfs_3_20050807_0000_fff.ctl	28 KB
gfs_3_20050807_0000_fff.idx	511 KB	gfs_3_20050807_0600_000.grb	24180 KB
gfs_3_20050807_0600_fff.ctl	28 KB	gfs_3_20050807_0600_fff.idx	511 KB
gfs_3_20050807_1800_000.grb	24225 KB	gfs_3_20050807_1800_fff.ctl	28 KB
gfs_3_20050807_1800_fff.idx	511 KB	gfs_3_20050807_hh00_000.ctl	28 KB
gfs_3_20050807_hh00_000.idx	41 KB	gfs_3_20050808_0000_000.grb	24262 KB
gfs_3_20050808_0000_fff.ctl	28 KB	gfs_3_20050808_0000_fff.idx	511 KB
landmask	4 KB	masks.dat	< 1 KB
nomads-order-5962.cfg	< 1 KB		

You can also select files by entering a string below (*=any-string ?=1 character).

Select files

Grib Filter

Grib Filter: Many times you may only want a section of a huge data file. Rather than transferring the entire file, this section will allow you to select some or all (1) levels, (2) variables, and (3) dates of a GRIB file. The buttons represent common choices which may or may not be relevant to the files that you want transferred. For example choosing RH (relative humidity) would be pointless in file of sea-surface temperatures. In addition, not all possibilities are allowed. For example, suppose you only want the virtual temperature at the tropopause at 01Z. Too bad because you have to transfer the entire file.

Figure 3

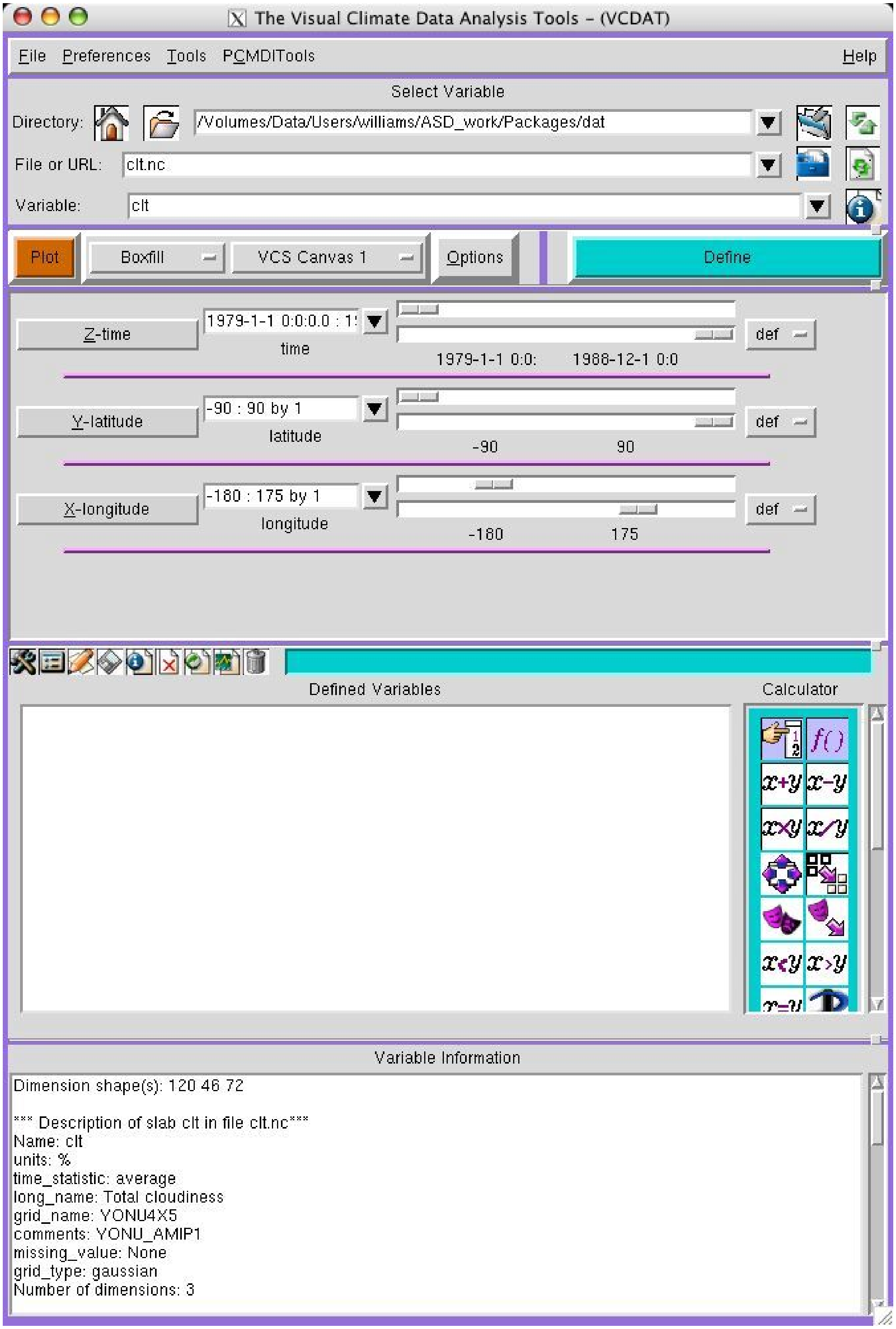

The Visual Climate Data Analysis Tools - (VCDAT)
File Preferences Tools PCMDITools Help
Select Variable
Directory: /Volumes/Data/Users/williams/ASD_work/Packages/dat
File or URL: clt.nc
Variable: clt
Plot
Boxfill
VCS Canvas 1
Options
Define
Z-time
1979-1-1 0:0:0.0 : 1
time
1979-1-1 0:0: 1988-12-1 0:0
def
Y-latitude
-90 : 90 by 1
latitude
-90 90
def
X-longitude
-180 : 175 by 1
longitude
-180 175
def
Defined Variables
Calculator
Variable Information
Dimension shape(s): 120 46 72
*** Description of slab clt in file clt.nc***
Name: clt
units: %
time_statistic: average
long_name: Total cloudiness
grid_name: YONU4X5
comments: YONU_AMIP1
missing_value: None
grid_type: gaussian
Number of dimensions: 3

Figure 4

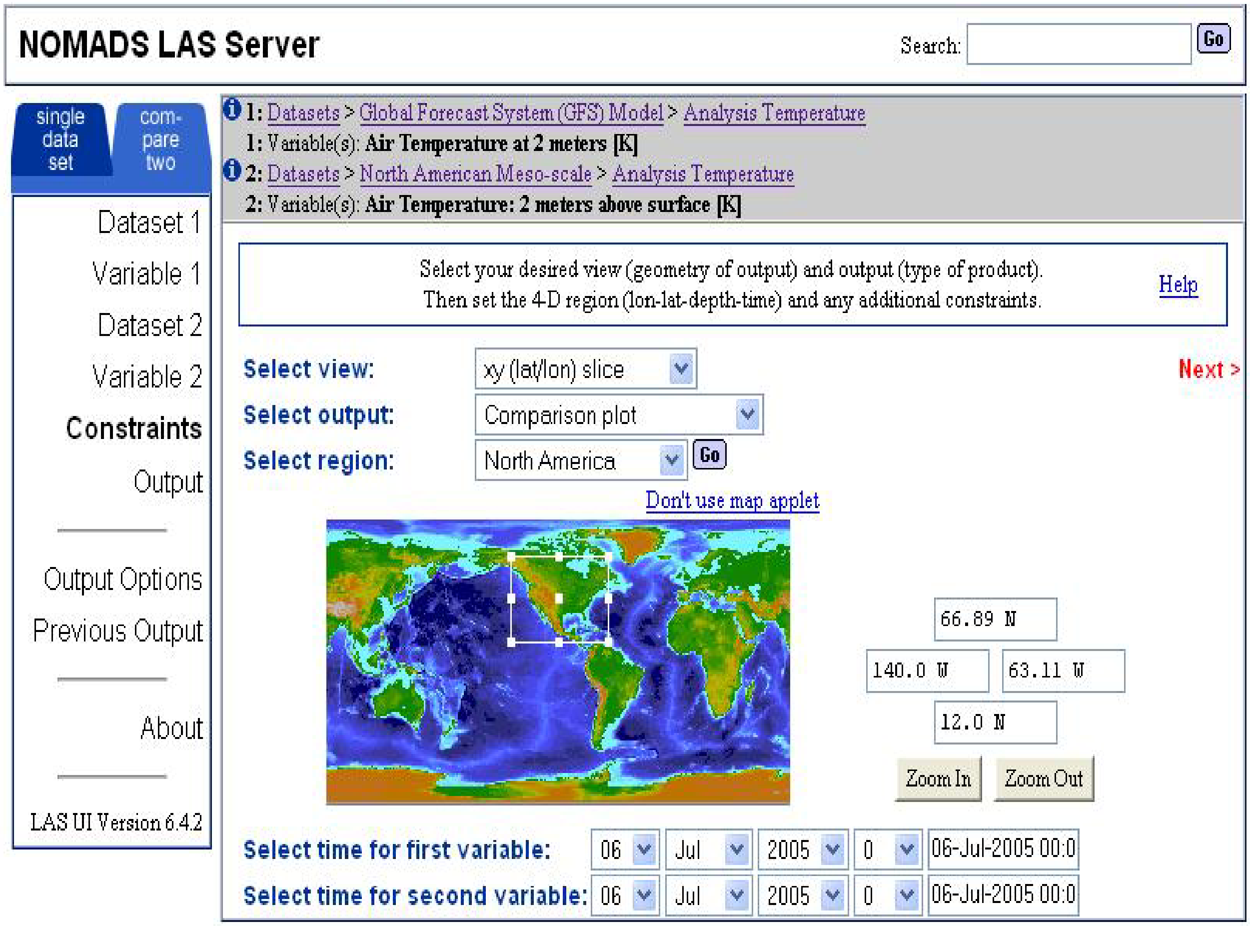

NOMADS LAS Server
Search:
Go
single data set
com-pare two
Dataset 1
Variable 1
Dataset 2
Variable 2
Constraints
Output
Output Options
Previous Output
About
LAS UI Version 6.4.2
1: Datasets > Global Forecast System (GFS) Model > Analysis Temperature
1: Variable(s): Air Temperature at 2 meters [K]
2: Datasets > North American Meso-scale > Analysis Temperature
2: Variable(s): Air Temperature: 2 meters above surface [K]
Select your desired view (geometry of output) and output (type of product).
Then set the 4-D region (lon-lat-depth-time) and any additional constraints.
Help
Select view:
xy (lat/lon) slice
Next >
Select output:
Comparison plot
Select region:
North America
Go
Don't use map applet
66.89 N
140.0 W
63.11 W
12.0 N
Zoom In
Zoom Out
Select time for first variable:
06
Jul
2005
0
06-Jul-2005 00:0
Select time for second variable:
06
Jul
2005
0
06-Jul-2005 00:0

Figure 5

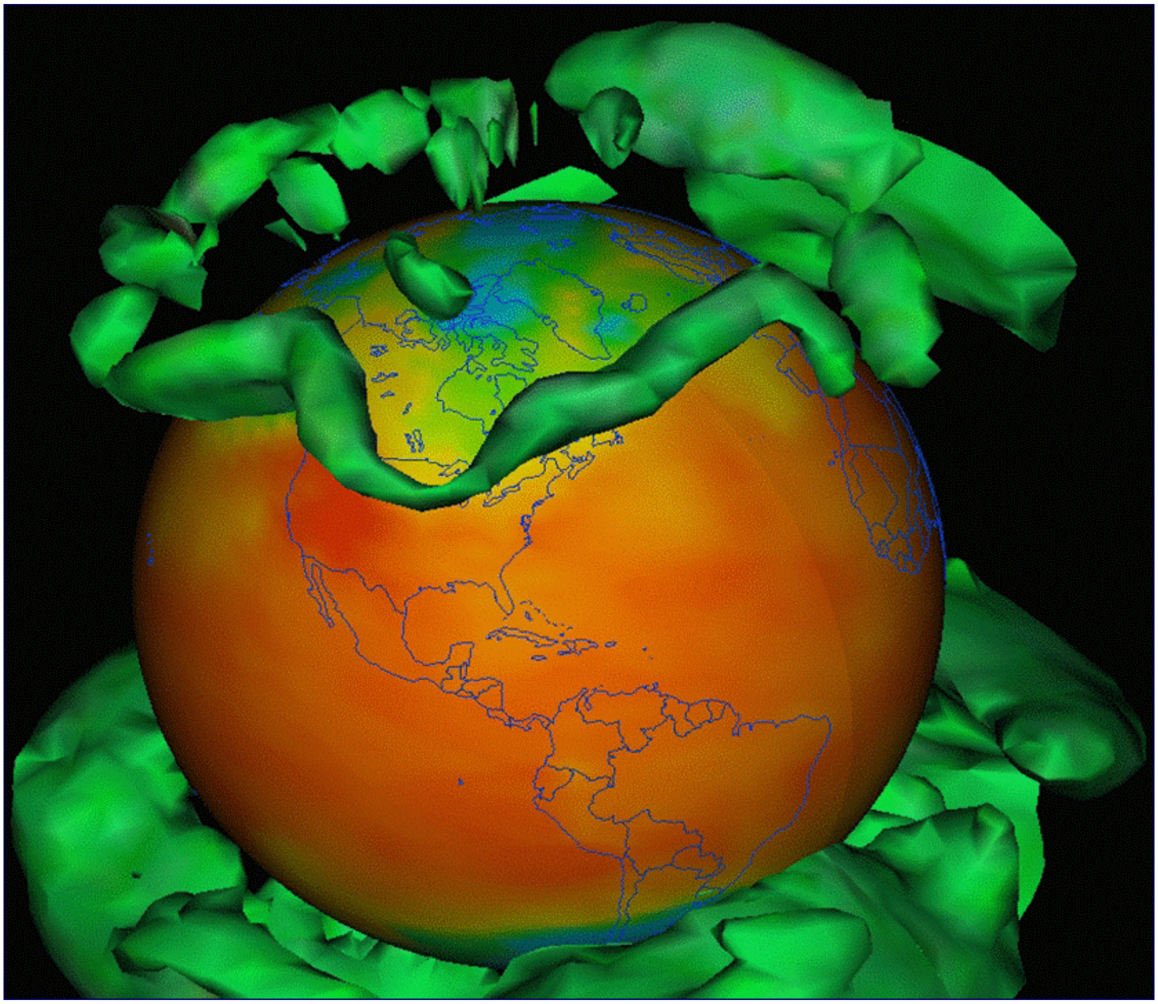


Figure 6.

NCDC NOMADS GrADS Server - top level - NCDC_NOAAPort_ETA - 200311 - 20031106 - meso-eta_212_20031106_0000_fff

NCDC NOMADS GrADS Server - info for /NCDC_NOAAPort_ETA/200311/20031106

dds das

DODS URL: http://nomads.ncdc.noaa.gov:9090/dods/NCDC_NOAAPort_ETA/200311/20031106/meso-eta_212_20031106_0000_fff

Description:	Analysis and 3 hour forecasts from 00Z06nov2003 run.	
Documentation:	none provided	
Longitude:	-154°E to -49°E	(421 points, avg. res. 0.25°)
Latitude:	10°N to 62.5°N	(211 points, avg. res. 0.25°)
Altitude:	1000 to 100	(29 points, avg. res. 32.14)
Time:	00Z06NOV2003 to 12Z08NOV2003	(21 points, avg. res. 3.0 hours)
Variables:	**(total of 25)**	
rh	relative humidity [%]	
cape	convective available potential energy (surface) [j/kg]	
cins	convective inhibition (surface) [j/kg]	
cnwatsfc	surface plant canopy surface water [kg/m^2]	
p	total precipitation [kg/m^2]	
pc	convective precipitation [kg/m^2]	
slp	sea level pressure [pa]	
slpe	sea level pressure, eta reduction [pa]	
snow	accumulated snow depth (water equivalent) [kg/m^2]	
soilm0	volumetric soil moisture, 0 to 10cm [fraction]	
soilm010	volumetric soil moisture, 10 to 40cm [fraction]	
soilm040	volumetric soil moisture, 40 to 100cm [fraction]	
soilm100	volumetric soil moisture, 100 to 200cm [fraction]	
soilt0	underground soil temperature 0- 10cm[k]	
soilt010	underground soil temperature 10- 40cm[k]	
soilt040	underground soil temperature 40-100cm[k]	
soilt100	underground soil temperature 100-200cm[k]	
t	temperature [k]	
u	u winds [m/s]	
v	v winds [m/s]	

Figure 7

Model Availability on NCDC NOMADS						
Model	**Grid**	**Domain**	**Resolution**	**Cycles**	**Forecasts**	**Levels and [variables]**
NAM MESO-ETA	218	United States	12.19 Km	6 Hours	3 Hrs. to 60	141 total variables, with 39 Vertical Levels [8]
GFS	003	Global	1 degree Lat/Lon	6 Hours	3 Hrs. to 180	139 Total variables, with 26 Vertical Levels [8]
Ensembles	3	Global	1 degree Lat/Lon	6 Hours	6 Hrs. to 180	134 Total variables, with 26 Vertical Levels [8]
SREF	212	United States	0.25 degree Lat/Lon	12 Hours at 09Z and 21Z	3 Hrs. to 63	169 Total variables, with 39 Vertical Levels
CFS	2	Global	2.5 degree Lat/Lon	00Z, Jan 1-3,9-13,19-23,last day. 1981-2003	Monthly Avg Jan-Sep	64 Total variables, with 5 Vertical Levels
AOA-RTMA	3	Global	1 degree Lat/Lon	6 Hours	Anal/6 Hr. Guess	134 Total variables, with 26 Vertical Levels [8]
Global 0.5	4	Global	0.5 degree Lat/lon	6 Hours	3 Hrs. to 180	163 Total variables, with 42 Vertical Levels
RUC-13	236	United States	~0.2 egree Lat/Lon	1 Hours	1 Hrs. to 12	92 Total variables, with 37 Vertical Levels
NDFD	221	United States	~5.0km	1 Hours	1 Hrs. to 21	Tbd

NCEP North American Regional Reanalysis (NARR) Available on NCDC NOMADS						
Model	**Grid**	**Domain**	**Resolution**	**Cycles**	**Forecasts**	**Levels and [variables]**
NARR	221(a)	North America	32.46 Km	3 Hours	None	29 Vertical Levels [8], with 187 Total Variables
NARR	221(b)	North America	32.46	3 Hours	3 Hrs	29 Vertical Levels [8], with 187 Total Variables
NARR Monthly Means A	221(a)	North America	32.46	3 Hours	None	Monthly Avg of all analysis fields
NARR Monthly Means B	221(b)	North America	32.46	3 Hours	3 Hrs	Monthly Avg of all fcst fields
NARR Monthly 3-hrly means A	221(a)	North America	32.46	3 Hours	None	Monthly 3-hrly timestep Avg of all analysis fields (00-03Z, 03-06Z, etc.)
NARR Monthly 3-hrly means B	221(b)	North America	32.46	3 Hours	3 Hrs	Monthly 3-hrly timesteps Avg of all fcst fields

Table 1. NCEP NWP Availability: Real-Time and Historical

Period of Record for NOMADS Datasets

As of August 8, 2005

NOAAPort (Historical Only)

Model System	**Grid**	**Online Availability*1**	**Availability from deep archive**
GFS (AVN)	ALL	June 1, 2003 to May 5, 2005	May 01, 2002 to May 31, 2003
GFS (MRF)	201	June 1, 2003 to May 5, 2005	May 01, 2002 to May 31, 2003
	202		
	203	July 1, 2003 to May 5, 2005	January 17, 2003 to May 31, 2003
	205		
NAM Early-ETA	212	June 1, 2003 to May 5, 2005	July 27, 2002 to May 31, 2003
NAM Meso-ETA	211	June 1, 2003 to May 5, 2005	July 27, 2002 to May 31, 2003
	212		
	215		
	218	June 1, 2003 to May 5, 2005	October 02, 2002 to May 31, 2003
RUC	211	June 1, 2003 to May 5, 2005	July 27, 2002 to May 31, 2003
RUC2	536	June 1, 2003 to May 5, 2005	July 27, 2002 to May 31, 2003
		Real-Time and Historical	
NAM MESO-ETA High Resolution	003	Jan 01, 2005 to Present	March 01, 2004 to December 31, 2004
GFS High Resolution	218	Jan 01, 2005 to Present	March 01, 2004 to December 31, 2004
North American Regional Reanalysis	221	January 01, 1979 to present (2005 in processing)	This dataset is completely online
Ensembles		Real-Time (see *Note 2)	Currently being Ingested
SREF		Note 2	
CFS		Note 2	
AOR-RTMA		Note 2	
Global 0.5		Note 2	
RUC-13		Note 2	
GDAS SSI Model Input		Note 2	
*** Note1:**		Reduced variable and resolution NOAAPort girds discontinued on May 5, 2005 and replaced by higher resolution NCEP NAM and GFS, Grids 003 and 218	
*** Note 2:**		The Real-time data is available at NCEP and available for up to two weeks. These data, at the time of this writing, are being provided or soon to be provided to NCDC for long term preservation and NOMADS access.	

Table 2. Period of Record for NOMADS model data at NCDC